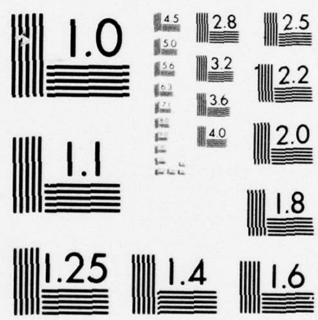
AD-A053 844 NAVAL RESEARCH LAB WASHINGTON D C F/G 4/1
THE EFFECTS OF GEOMAGNETIC FIELD ALIGNED POTENTIAL DIFFERENCES --ETC(U)
JAN 78 J H OWENS, J FEDDER
UNCLASSIFIED NRL-MR-3573 SBIE-AD-E000 141 NL

| OF |
AD
A053844

END
DATE
FILMED
6-78
DDC


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

4/3/78

ade000141

NRL Memorandum Report 3573

The Effects of Geomagnetic Field Aligned Potential Differences on Precipitating Magnetospheric Particles

J. H. ORENS AND J. FEDDER

Plasma Physics Division

12

January 1978

This research was sponsored by the Defense Nuclear Agency under Subtask No. SS9QAXHC066, Late Time Effects, work unit 04, Electrostatic-Ion Plume.

NAVAL RESEARCH LABORATORY
Washington, D.C.

(14) NRL-MR-3573

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3573	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) THE EFFECTS OF GEOMAGNETIC FIELD ALIGNED POTENTIAL DIFFERENCES ON PRECIPITATING MAGNETOSPHERIC PARTICLES		5. TYPE OF REPORT & PERIOD COVERED (9) Interim Report on a continuing NRL Problem
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Joseph H./Owens, Joel/Fedder J. H. Orens and J. Fedder		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem H02-41 DNA Project No. S99QAXHC066
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE (11) Jan[redacted]978
		13. NUMBER OF PAGES 30 (12) 12p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) S99QAXH (17) C066		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited. (18) SBIE

(19) AD-E000 141

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This research was sponsored by the Defense Nuclear Agency under Subtask No. S99QAXHC066, Late Time Effects, Work Unit 4, Electrostatic-Ion Plume.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aurora
Magnetic mirror

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Mirroring of energetic ions and electrons between the magnetosphere and the ionosphere could by one possible mechanism for the precipitation of energetic particles necessary for the proper modeling of the auroral plasma. This paper considers the increased trapping or detrapping of particles in the ionosphere-magnetosphere mirror system caused by an electric potential difference along the geomagnetic field. It is found that the effect of this potential difference can be quite important to the proper modeling of the high latitude auroral plasma, but is of lesser importance for the high energy Van Allen belts.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 950 JOB

CONTENTS

THE EFFECTS OF GEOMAGNETIC FIELD ALIGNED POTENTIAL DIFFERENCES ON PRECIPITATING MAGNETOSPHERIC PARTICLES

I. INTRODUCTION

The occurrence and proper modeling of the auroral plasma requires a source of energetic particles and a mechanism for their precipitation. The source of this auroral plasma is the magnetosphere, a large reservoir of energetic ions and electrons. Moreover, the effects of the mirroring of these particles between the magnetosphere and the ionosphere could be one possible mechanism for their precipitation. Therefore it is of interest to consider the mapping of certain magnetospheric regions into their corresponding ionospheric regions by tracing the geomagnetic field lines. Accordingly, the plasma sheet region of the magnetosphere maps into the high latitude region of the diffuse aurora while the Van Allen radiation belts map into the lower latitude ionosphere.

The plasma sheet is a region of ions and electrons having an isotropic Maxwellian velocity distribution at an energy of a few Kev's [1]. Particles are continually leaking out of this region to form the diffuse aurora [2,3]. Such fluxes arise from the transmission of the particles through the ends of the geomagnetic mirror that exists between the plasma sheet and the high latitude ionosphere. The Van Allen belts are another group of particles having a loss cone velocity distribution at a higher energy of a few tens of Kev's to a few Mev's [4]. Under the proper conditions, a fraction of the particles in this region can also reach the ionosphere by being transmitted through the ends of its corresponding geomagnetic mirror. Characterizing end

Manuscript submitted July 20, 1977.

losses from a magnetic mirror is a familiar problem not only in auroral studies, but also in the investigation of machines for controlled thermonuclear fusion.

This paper considers the increased trapping or detrapping of particles in the ionsphere-magnetosphere mirror system caused by an electric potential difference along the geomagnetic field. This potential difference enhances or diminishes the number of precipitating particles depending on its sign and the charge of the particles. Such potential differences can arise due to the resistivity along the magnetic field to field aligned currents. These currents have been calculated in our auroral models and lead to potential differences on the order of Kev's [5]. The occurrence of a potential difference not only modulates the precipitating fluxes, but also modifies the auroral precipitation patterns and the auroral particle energies; all of which can lead to changes in the model results.

II. END LOSSES FOR A MAGNETIC MIRROR WITH A FIELD ALIGNED POTENTIAL

Conservation of energy for a particle of mass m and charge q in a magnetic mirroring system $B(z)$ with a potential distribution $\phi(z)$ requires that:

$$1/2mV_{\parallel}^2(z) + \mu B(z) + q\phi(z) = \text{constant} \tag{1}$$

where μ, the magnetic moment, is an adiabatic invariant.

$$\mu = \frac{1/2mV_{\perp}^2(z)}{B(z)} \tag{2}$$

If we take $z = 0$ to be the center of a step magnetic mirror and allow for a step potential well at the mirror boundary $z = M$, we have the two possible configurations shown in Figure 1. For these configurations equation (1) can be written in the form:

$$1/2mV_{\parallel}^2(z) + mV_{\perp}^2(0)\frac{B(z)}{B(0)} + q\phi(z) = 1/2mV^2(0) \tag{3}$$

where we have utilized the invariance of μ. For a particle to be transmitted through the mirror requires that:

$$1/2mV_{\parallel}^2(M) > 0. \tag{4}$$

Applying equation (4) to equation (3) then yields the condition on the velocities at $z = 0$ for transmission

$$V_{\perp}^2(0) < \frac{B(0)/B(M)}{1 - B(0)/B(M)}\left[V_{\parallel}^2(0) - \frac{2q\phi(M)}{m}\right]. \tag{5}$$

Since we are only considering the $+z$ side of the magnetic step we need only consider the region where $V_{\parallel}(0) > 0$. Figure 2 displays the region of velocities at $z = 0$ that are transmitted through the mirror for the two configurations of Figure 1.

Assume a Maxwellian velocity distribution interior to the mirror

$$f = \frac{n}{\left(\frac{2}{3}\pi\right)^{3/2} V_T^3}\exp\left[-\frac{3}{2}\left(\frac{V_{\perp}^2 + V_{\parallel}^2}{V_T^2}\right)\right] \tag{6}$$

in cylindrical coordinates where n is the particle density and V_T is the thermal velocity. First consider the detrapping case where $q\phi(M) < 0$. The flux at $z = 0$ transmitted through the mirror is then:

$$F_T = \int_0^{\infty}\int_0^{V_{\perp}(0)}\int_0^{2\pi}\frac{nV_{\parallel}(0)}{\left(\frac{2}{3}\pi\right)^{3/2} V_T^3}\exp\left\{-\frac{3}{2}\left[\frac{V_{\perp}^2(0) + V_{\parallel}^2(0)}{V_T^2}\right]\right\} dV_{\perp}(0)\,dV_{\parallel}(0) \tag{7a}$$

where

$$V_\perp^2(0) = \frac{B(0)/B(M)}{1 - B(0)/B(M)}\left[V_{\parallel}^2(0) - \frac{2q\phi(M)}{m}\right]. \tag{7b}$$

Performing the integration leads to:

$$F_T = \frac{nV_T}{\sqrt{6\pi}}\left\{1 - \left[1 - \frac{B(0)}{B(M)}\right]\exp\left[\frac{B(0)/B(M)}{1 - B(0)/B(M)}\,\frac{q\phi(M)}{KT}\right]\right\} \tag{8a}$$

where

$$\frac{1}{2}mV_T^2 = \frac{3}{2}KT. \tag{8b}$$

Now consider the trapping case where $q\phi(M) > 0$. Here the flux at $z = 0$ transmitted through the mirror is:

$$F_T = \int_{\sqrt{2q\phi(M)/m}}^{\infty}\int_0^{V_\perp(0)}\int_0^{2\pi}\frac{nV_{\parallel}(0)}{\left[\frac{2}{3}\pi\right]^{3/2}V_T^3}\exp\left\{-\frac{3}{2}\left[\frac{V_\perp^2(0) + V_{\parallel}^2(0)}{V_T^2}\right]\right\}dV_\perp(0)\,dV_{\parallel}(0) \tag{9}$$

which yields after integration:

$$F_T = \frac{nV_T}{\sqrt{6\pi}}\,\frac{B(0)}{B(M)}\exp\left[-\frac{q\phi(M)}{kT}\right]. \tag{10}$$

Similarly the total flux at $z = 0$ travelling toward the mirror is

$$F = \frac{nV_T}{\sqrt{6\pi}}. \tag{11}$$

Utilizing equations (8a), (10), and (11) we can define a transmission coefficient ($T = F_T/F$) for the two cases. For the detrapping case

$$T_{\text{Detrapping}} = 1 - \left[1 - \frac{B(0)}{B(M)}\right]\exp\left[\frac{B(0)/B(M)}{1 - B(0)/B(M)}\,\frac{q\phi(M)}{kT}\right] \tag{12a}$$

$$\frac{q\phi(M)}{kT} < 0 \tag{12b}$$

and for the trapping case

$$T_{\text{Trapping}} = \frac{B(0)}{B(M)} \exp\left[- \frac{q\phi(M)}{kT} \right] \tag{13a}$$

$$\frac{q\phi(M)}{kT} > 0. \tag{13b}$$

In the potential free case $\left(\frac{q\phi(M)}{kT} = 0\right)$ both equations (12a) and (13a) reduce to the familiar result

$$T = \frac{B(0)}{B(M)}. \tag{14}$$

For certain applications it is of interest to expand equation (12a) in the limit of large mirror ratio $\left(\frac{B(M)}{B(0)} >> 1\right)$ and/or a small potential difference $\left(-1 << \frac{q\phi(M)}{kT} < 0\right)$. Such an expansion yields

$$T_{\text{Detrapping}} \simeq \frac{B(0)}{B(M)} \left[1 - \frac{q\phi(M)}{kT} \right]. \tag{15}$$

Since for this case $\frac{q\phi(M)}{kT} < 0$, the potential produces an enhancement to the transmission coefficient for a simple magnetic mirror given by equation (14). Similarly expanding equation (13a) in the limit of a small potential difference $\left(0 < \frac{q\phi(M)}{kT} << 1\right)$ leads to:

$$T_{\text{Trapping}} \simeq \frac{B(0)}{B(M)} \left[1 - \frac{q\phi(M)}{kT} \right]. \tag{16}$$

Since for this case $\frac{q\phi(M)}{kT} > 0$, the potential produces a decrease in the transmission coefficient of equation (14).

III. DISCUSSION

The two most important equations from the preceding section are the systems (12) and (13) which prescribe the transmission coefficients for the two possible charge states and potential differences. It is important to observe that the quantity $q\phi(M)$ determines whether trapping or detrapping of particles occurs. For electrons a positive potential difference along the geomagnetic field (i.e. the ionosphere charged positive relative to the magnetosphere) produces an enhanced precipitation, while for ions a corresponding negative potential difference has the same effect. It is also relevant to note that in the absence of a field aligned potential difference more electrons will precipitate from a given charge neutral system of Maxwellian electrons and ions having equal temperatures, since the flux, equation (11), varies directly with the thermal velocity. The thermal velocities of equal temperature electrons and ions are in inverse proportion to the square root of their respective masses.

We will now present some examples of these effects for plasmas in the earth's magnetosphere. The geomagnetic mirror ratio $B(0)/B(M)$ between the plasma sheet and the high latitude ionosphere ranges between 2×10^{-2} and 5×10^{-4} [4]. The ambient plasma sheet density is approximately 1 particle/cm^3 with a temperature of a few Kev's [1,4]. Therefore, in the absence of any potential difference along the magnetic field, there is a flux of precipitating electrons on the order of 5×10^8 electrons/cm^2-sec and a corresponding flux of ions on the order of 10^7 ions/cm^2-sec. Recent satellite observations of diffuse aurora have shown precipitating fluxes of these magnitudes [6]. Such a difference in the precipitating fluxes would usually lead to charge build up and a subsequent equalization of the fluxes. This does not occur in the ionosphere due to the presence of highly mobile ambient cold electrons, which can flow out of the ionosphere in order to neutralize the charge build up created by the high energy electron

flux. Since the plasma sheet remains essentially an isotropic Maxwellian distribution of particles, either equation (12) or (13), depending on the sign of $q\phi(M)$, will govern the precipitation in the presence of a potential difference. Our auroral models have shown that potential differences on the order of Kev's are likely to exist along the geomagnetic field lines [5]. Therefore the precipitation from the plasma sheet can vary from more that twice to less than one-half that of the potential free state.

For the Van Allen belts the geomagnetic mirror ratio is generally less than .02 and the ambient density is less than .1 particle/cm^3 [4]. Since the ambient particles have a loss cone distribution at tens of Kev's to a few Mev's, there is negligible precipitation in the absence of a large potential difference or a strong pitch angle scattering mechanism. In fact only equation (15) from the preceding section has any practical application for this region, but it needs to be modified to reflect the fact that there are no particles within the loss cone,

$$\frac{V_\perp^2(0)}{V_\parallel^2(0)} < \frac{B(0)/B(M)}{1 - B(0)/B(M)}.$$

Considering this the transmission coefficient for the Van Allen belts, in the limit of a small potential difference, is given as:

$$T_{\text{Detrapping}} \simeq -\frac{B(0)}{B(M)} \frac{q\phi(M)}{kT} \tag{17a}$$

$$-1 << \frac{q\phi(M)}{kT} < 0. \tag{17b}$$

From equations (11) and (17a) the precipitating flux can be calculated for any given potential difference. Such a flux is likely to be small except during very large geomagnetic disturbances.

From the preceding results, we can draw the following conclusions:

1. Enhanced or diminished particle precipitation due to field aligned potential differences is likely to be quite important to the proper modeling of the high latitude auroral plasma since

potential drops due to the strong geomagnetic field aligned currents can be sizable fractions of the electron and ion energies in the plasma sheet. As we have shown potential differences of this magnitude can lead to a large modulation of the auroral precipitation fluxes.

2. Conversely, for the high energy Van Allen belts such a mechanism is not likely to be significant since except for highly disturbed times it is very difficult to get field aligned potential differences much greater than a few Kev's; therefore the potential difference will only be a very small fraction of the particles' ambient energy.

REFERENCES

1. L.A. Frank, K. L. Ackerson, and R.P. Lepping, "On Hot Tenueous Plasmas, Fireballs and Boundary Layers in the Earth's Magnetotail," J. Geophys. Res. **81** 5859 (1976).
2. D.A. Gurnett and L.A. Frank, "Observed Relationship Between Electric Fields and Auroral Particle Precipitation," J. Geophys. Res. **78** 145 (1973).
3. L.A. Frank, N.A. Saflekos, and K.L. Ackerson, "Electron Precipitation in the Post Midnight Sector of the Auroral Zones," J. Geophys. Res. **81** 155 (1976).
4. S. Akasofu and S. Chapman, *Solar — Terrestrial Physics*, The International Series of Monographs on Physics, Chapter 6, Oxford at The Clarendon Press, 1972.
5. J.A. Fedder and J.H. Orens, "Aurora Arc Modeling," NRL Memo-Report 3120, October 1975.
6. A.T.Y. Lui et al., "Simultaneous Observations of Particle Precipitations and Auroral Emissions by the ISIS 2 Satellite in the 19-24 MLT Sector," J. Geophys. Res. **82** 2210 (1977).

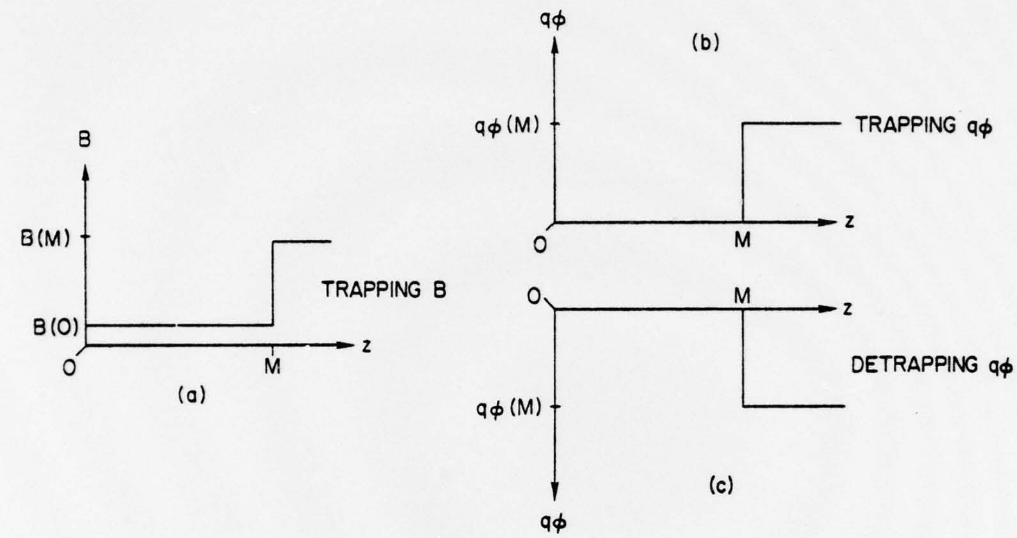


Fig. 1 – (a) A trapping step magnetic well configuration; (b) A trapping step potential well configuration where $q\phi(M) > 0$; and (c) A detrapping step potential well configuration where $q\phi(M) < 0$.

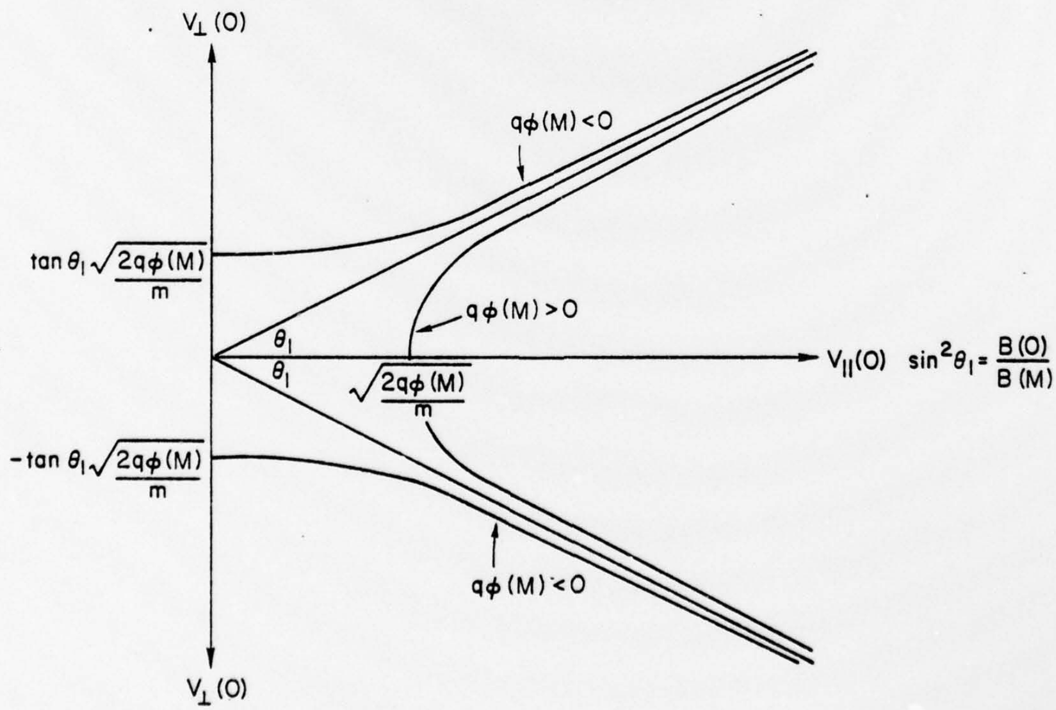


Fig. 2 – The region of velocity space at $z = 0$ that is transmitted through the mirroring system for the two potential configurations of Figure 1. The region to the right of the respective curves represents the transmitted velocity space.

DEPARTMENT OF DEFENSE

DIRECTOR
COMMAND CONTROL TECHNICAL CENTER
PENTAGON RM BE 685
WASHINGTON, D.C. 20301
01CY ATTN C-650 G. C. JONES
01CY ATTN C-650 W. HEIDIG
01CY ATTN C-312 R. MASON

DIRECTOR
DEFENSE ADVANCED RSCH PROJ AGENCY
ARCHITECT BUILDING
1400 WILSON BLVD.
ARLINGTON, VA. 22209
01CY ATTN NUCLEAR MONITORING RESEARCH
01CY ATTN STRATEGIC TECH OFFICE

DEFENSE COMMUNICATION ENGINEER CENTER
1860 WIEHLE AVENUE
RESTON, VA. 22090
01CY ATTN CODE R820 R. L. CRAWFORD
01CY ATTN CODE R410 JAMES W. MCLEAN

DIRECTOR
DEFENSE COMMUNICATIONS AGENCY
WASHINGTON, D.C. 20305
(ADR CNWDI: ATTN CODE 240 FOR)
01CY ATTN CODE 480
01CY ATTN CODE 810 R. W. ROSTRON
01CY ATTN CODE 101B MAJ R. ROOD
01CY ATTN MAUREY RAFFENSPERGER

DEFENSE DOCUMENTATION CENTER
CAMERON STATION
ALEXANDRIA, VA. 22314
(12 COPIES IF OPEN PUBLICATION, OTHERWISE 2 COPIES)
12CY ATTN TC

DIRECTOR
DEFENSE INTELLIGENCE AGENCY
WASHINGTON, D.C. 20301
01CY ATTN DT-1B
01CY ATTN W. WITTIG DC-7D

DIRECTOR
DEFENSE NUCLEAR AGENCY
WASHINGTON, D.C. 20305
    01CY ATTN STSI ARCHIVES
    01CY ATTN STVL
    03CY ATTN STTL TECH LIBRARY
    01CY ATTN DDST
    03CY ATTN RAAE

DIR OF DEFENSE RSCH & ENGINEERING
DEPARTMENT OF DEFENSE
WASHINGTON, D.C. 20301
    01CY ATTN S&SS (OS)

COMMANDER
FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRTLAND AFB, NM 87115
    01CY ATTN FCPR

DIRECTOR
INTERSERVICE NUCLEAR WEAPONS SCHOOL
KIRTLAND AFB, NM 87115
    01CY ATTN DOCUMENT CONTROL

DIRECTOR
JOINT STRAT TGT PLANNING STAFF JCS
OFFUTT AFB
OMAHA, NB 68113
    01CY ATTN JLTW-2
    01CY ATTN JPST CAPT G. D. GOETZ

CHIEF
LIVERMORE DIVISION FLD COMMAND DNA
LAWRENCE LIVERMORE LABORATORY
P. O. BOX 808
LIVERMORE, CA 94550
    01CY ATTN FCPRL

DIRECTOR
NATIONAL SECURITY AGENCY
FT. GEORGE G. MEADE, MD 20755
    01CY ATTN JOHN SKILLMAN R52
    01CY ATTN FRANK LEONARD
    01CY ATTN W14 PAT CLARK

OJCS/J-3
THE PENTAGON
WASHINGTON, D.C. 20301
(OPERATIONS)
01CY ATTN WWMCCS EVAL OFC MR. TOMA

ASD (C31) (SYSTEMS)
3D224, THE PENTAGON
WASHINGTON, D.C. 20301
01CY ATTN DR. M. EPSTEIN
01CY DR. J. BABCOCK

WWMCCS SYSTEM ENGINEERING ORG
WASHINGTON, D.C. 20305
01CY ATTN R. L. CRAWFORD

COMMANDER/DIRECTOR
ATMOSPHERIC SCIENCES LABORATORY
U.S. ARMY ELECTRONICS COMMAND
WHITE SANDS MISSILE RANGE, NM 88002
01CY ATTN DRSEL-BL-SY-S F. E. NILES

DIRECTOR
BMD ADVANCED TECH CTR
HUNTSVILLE OFFICE
P. O. BOX 1500
HUNTSVILLE, AL 35807
01CY ATTN ATC-T MELVIN T. CAPPS
01CY ATTN ATC-O W. DAVIES
01CY ATTN ATC-R DON RUSS

PROGRAM MANAGER
BMD PROGRAM OFFICE
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333
01CY ATTN DACS-BMT JOHN SHEA

CHIEF C-E SERVICES DIVISION
U.S. ARMY COMMUNICATIONS CMD
PENTAGON RM 1B269
WASHINGTON, D.C. 20310
01CY ATTN CC-OPS-CE

COMMANDER
HARRY DIAMOND LABORATORIES
2800 POWDER MILL ROAD
ADELPHI, MD 20783
(CNWDI-INNER ENVELOPE: ATTN: DRXDO-RBH)
01CY ATTN MILDRED H. WEINER DRXDO-TI
01CY ATTN DRXDO-RB ROBERT WILLIAMS
01CY ATTN DRXDO-NP FRANCIS N. WIMENITZ
01CY ATTN DRXDO-NP CYRUS MOAZED

DIRECTOR
TRASANA
WHITE SANDS MISSILE RANGE, NM 88002
01CY ATTN ATAA-SA
01CY ATTN TCC/F. PAYAN JR
01CY ATTN ATAA-TAC LTC JOHN HESSE

COMMANDER
U.S. ARMY COMM-ELEC ENGRG INSTAL AGY
FT. HUACHUCA, AZ 85613

01CY ATTN EED-PED GEORGE LANE

COMMANDER
U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NJ 07703
01CY ATTN DRSEL-NL-RD H. S. BENNET
01CY ATTN DRSEL-PL-ENV HANS A. BOMKE

COMMANDER
U.S. ARMY FOREIGN SCIENCE & TECH CTR
220 7TH STREET, NE
CHARLOTTESVILLE, VA 22901
01CY ATTN P. A. CROWLEY
01CY ATTN R. JONES

COMMANDER
U.S. ARMY MATERIEL DEV & READINESS CMD
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333
01CY ATTN DRCLDC J. A. BENDER

COMMANDER
U.S. ARMY NUCLEAR AGENCY
FORT BLISS, TX 79916
    01CY ATTN MONA-WE J. BERBERET

DIRECTOR
U.S. ARMY BALLISTIC RESEARCH LABS
ABERDEEN PROVING GROUND, MD 21005
    01CY ATTN LAWRENCE J. PUCKETT

COMMANDER
U.S. ARMY SATCOM AGENCY
FT. MONMOUTH, NJ 07703
    01CY ATTN DOCUMENT CONTROL

COMMANDER
U.S. ARMY MISSILE INTELLIGENCE AGENCY
REDSTONE ARSENAL, AL 35809
    01CY ATTN JIM GAMBLE

CHIEF OF NAVAL OPERATIONS
NAVY DEPARTMENT
WASHINGTON, D.C. 20350
    01CY ATTN OP 943 LCDR HUFF
    01CY ATTN ALEXANDER BRANDT
    01CY ATTN RONALD E. PITKIN

CHIEF OF NAVAL RESEARCH
NAVY DEPARTMENT
ARLINGTON, VA 22217
    01CY ATTN CODE 418
    01CY ATTN CODE 461

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
NAVAL ELECTRONIC SYSTEMS CMD HQS
WASHINGTON, D.C. 20360
    01CY ATTN NAVALEX 034 T BARRY HUGHES
    01CY ATTN PME 117-T SATELLITE COMM PROJECT OFF
    01CY ATTN PME 117

COMMANDING OFFICER
NAVAL INTELLIGENCE SUPPORT CTR
4301 SUITLAND ROAD, BLDG. 5
WASHINGTON, D.C. 20390
    01CY ATTN MR. DUBBIN STIC 12

COMMANDER
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152
01CY ATTN WILLIAM F. MOLER
01CY ATTN CODE 0230 C. BAGGETT
03CY ATTN CODE 2200
01CY ATTN R. EASTMAN

DIRECTOR
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375
20CY ATTN CODE 7700 TIMOTHY P. COFFEY
03CY ATTN CODE 7701 JACK D. BROWN
100CY ATTN CODE 7750
01CY ATTN CODE 5400 BRUCE WALD
03CY ATTN CODE 5450 TELECOMMUNICATIONS SYSTEMS TECH.

COMMANDER
NAVAL SPACE SURVEILLANCE SYSTEM
DAHLGREN, VA 22448
01CY ATTN CAPT J. H. BURTON

COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD 20910
01CY ATTN CODE WA501 NAVY NUC PRGMS OFF

DIRECTOR
STRATEGIC SYSTEMS PROJECT OFFICE
NAVY DEPARTMENT
WASHINGTON, D.C. 20376
01CY ATTN NSP-2141
01CY ATTN NSSP-2722 FRED WIMBERLY

NAVAL SPACE SYSTEM ACTIVITY
P. O. BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CALIF. 90009
01CY ATTN A. B. HAZZARD

COMMANDER
ADC/DC
ENT AFB, CO 80912
01CY ATTN DC MR. LONG

COMMANDER
ADCOM/XPD
ENT AFB, CO 80912
    01CY ATTN XPQDQ

AF GEOPHYSICS LABORATORY, AFSC
HANSCOM AFB, MA 01731
    01CY ATTN OPR HAROLD GARDNER
    01CY ATTN OPR JAMES C. ULWICK
    01CY ATTN LKB KENNETH S. W. CHAMPION
    01CY ATTN OPR ALVA T. STAIR
    01CY ATTN SUOL RSCH LIB
    01CY ATTN PHP JULES AARONS
    01CY ATTN PHD JURGEN BUCHAU
    01CY ATTN PHD JOHN P. MULLEN

AF WEAPONS LABORATORY, AFSC
KIRTLAND AFB, NM 87117
    01CY ATTN SUL
    01CY ATTN CA ARTHUR H. GUENTHER
    01CY ATTN DYC CAPT L. WITTWER
    01CY ATTN SAS JOHN M. KAMM
    01CY ATTN DYC CAPT MARK A. FRY

AFTAC
PATRICK AFB, FL 32925
    01CY ATTN TF/MAJ WILEY
    01CY ATTN TN

AIR FORCE AVIONICS LABORATORY, AFSC
WRIGHT-PATTERSON AFB, OH 45433
    01CY ATTN AAD WADE HUNT
    01CY ATTN AFAL AAB H. M. HARTMAN
    01CY ATTN AAD ALLEN JOHNSON

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION/XR
HANSCOM AFB, MA 01731
    01CY ATTN XRC LTC J. MORIN
    01CY ATTN XRE LT MICHAELS

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION/YS
HANSCOM AFB, MA 01731
    01CY ATTN YSEV

COMMANDER
FOREIGN TECHNOLOGY DIVISION, AFSC
WRIGHT-PATTERSON AFB, OH 45433
01CY ATTN NICD LIBRARY
01CY ATTN ETD B. L. BALLARD

HQ USAF/RD
WASHINGTON, D.C. 20330
01CY ATTN RDQ

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
GRIFFISS AFB, NY 13440
01CY ATTN EMTLD DOC LIBRARY
01CY ATTN OCSE V. COYNE

SAMSO/SZ
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
(SPACE DEFENSE SYSTEMS)
01CY ATTN SZJ MAJOR LAWRENCE DOAN

COMMANDER IN CHIEF
STRATEGIC AIR COMMAND
OFFUTT AFB, NB 68113
01CY ATTN XPFS MAJ BRIAN G. STEPHAN
01CY ATTN ADWATE CAPT BRUCE BAUER
01CY ATTN NRT

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION (AFSC)
HANSCOM AFB, MA 01731
01CY ATTN JIM DEAS

SAMSO/YA
P. O. BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
01CY ATTN YAT CAPT L. BLACKWELDER

SAMSO/SK
P. O. BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
01CY ATTN SKA LT MARIA A. CLAVIN

SAMSO/MN
NORTON AFB, CA 92419
(MINUTEMAN)
    01CY ATTN MNNL LTC KENNEDY

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
HANSCOM AFB, MA 01733
    01CY ATTN ETEI A. LORENTZEN

U.S. ENERGY RSCH AND DEV ADMIN

EG&G, INC.
LOS ALAMOS DIVISION
P. O. BOX 809
LOS ALAMOS, NM 85544
    01CY ATTN JAMES R. BREEDLOVE

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
P. O. BOX 808
LIVERMORE, CA 94550
    01CY ATTN TECH INFO DEPT L-3
    01CY ATTN RONALD L. OTT L-531
    01CY ATTN DONALD R. DUNN L-156
    01CY ATTN RASPH S. HAGER L-31

LOS ALAMOS SCIENTIFIC LABORATORY
P. O. BOX 1663
LOS ALAMOS, NM 87545
    01CY ATTN DOC CON FOR ERIC LINDMAN
    01CY ATTN DOC CON FOR R. F. TASCHEK
    01CY ATTN DOC CON FOR ERIC JONES
    01CY ATTN DOC CON FOR JOHN S. MALIK
    01CY ATTN DOC CON FOR MARTIN TIERNEY J-10
    01CY ATTN DOC CON FOR JOHN ZINN

SANDIA LABORATORIES
P. O. BOX 5800
ALBUQUERQUE, NM 87115
    01CY ATTN DOC CON FOR J. P. MARTIN ORG 1732
    01CY ATTN DOC CON FOR W. D. BROWN ORG 1353
    01CY ATTN DOC CON FOR A. DEAN THORNBROUGH ORG 1245
    01CY ATTN DOC CON FOR T. WRIGHT
    01CY ATTN DOC CON FOR D. A. DAHLGREN ORG 1722

OTHER GOVERNMENT

DEPARTMENT OF COMMERCE
OFFICE OF TELECOMMUNICATIONS
INSTITUTE FOR TELECOM SCIENCE
BOULDER, CO 80302
01CY ATTN WILLIAM F. UTLAUT
01CY ATTN G. REED

NATIONAL OCEANIC & ATMOSPHERIC ADMIN
ENVIRONMENTAL RESEARCH LABORATORIES
DEPARTMENT OF COMMERCE
BOULDER, CO 80302
01CY ATTN JOSEPH H. POPE
01CY ATTN RICHARD GRUBB
01CY ATTN C. L. RUFFNACH

NASA
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD 20771
01CY ATTN ATS-6 OFC P. CORRIGAN

DEPARTMENT OF DEFENSE CONTRACTORS

AEROSPACE CORPORATION
P. O. BOX 92957
LOS ANGELES, CA 90009
    01CY ATTN IRVING M. GARFUNKEL
    01CY ATTN T. M. SALMI
    01CY ATTN V. JOSEPHSON
    01CY ATTN S. P. BOWER
    01CY ATTN N. D. STOCKWELL
    01CY ATTN P. P. OLSEN 120 RM 2224E
    01CY ATTN F. E. BOND RM 5003
    01CY ATTN J. E. CARTER 120 RM 2209
    01CY ATTN F. A. MORSE A6 RM 2407

ANALYTICAL SYSTEMS ENGINEERING CORP
5 OLD CONCORD ROAD
BURLINGTON, MA 01803
    01CY ATTN RADIO SCIENCES

BOEING COMPANY, THE
P. O. BOX 3707
SEATTLE, WA 98124
    01CY ATTN GLEN KEISTER
    01CY ATTN D. MURRAY

CALIFORNIA AT SAN DIEGO, UNIV OF
3175 MIRAMAR ROAD
LA JOLLA, CA 92037
    01CY ATTN HENRY G. BOOKER

BROWN ENGINEERING COMPANY, INC.
CUMMINGS RESEARCH PARK
HUNTSVILLE, AL 35807
    01CY ATTN ROMEO A. DELIBERIS

CHARLES STARK DRAPER LABORATORY, INC.
555 TECHNOLOGY SQUARE
CAMBRIDGE, MA 02139
    01CY ATTN D. B. COX
    01CY ATTN J. P. GILMORE MS 63

COMPUTER SCIENCES CORPORATION
P. O. BOX 530
6565 ARLINGTON BLVD
FALLS CHURCH, VA 22046
    01CY ATTN H. BLANK
    01CY ATTN JOHN SPOOR

COMSAT LABORATORIES
LINTHICUM ROAD
CLARKSBURG, MD 20734
    01CY ATTN R. R. TAUR

CORNELL UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING
ITHACA, NY 14850
    01CY ATTN D. T. FARLEY JR

FSL INC.
495 JAVA DRIVE
SUNNYVALE, CA 94086
    01CY ATTN R. K. STEVENS
    01CY ATTN J. ROBERTS
    01CY ATTN JAMES MARSHALL
    01CY ATTN V. L. MOWER
    01CY ATTN C. W. PRETTIE

FORD AEROSPACE & COMMUNICATIONS CORP
3939 FABIAN WAY
PALO ALTO, CA 94303
    01CY ATTN J. T. MATTINGLEY MS X22

GENERAL ELECTRIC COMPANY
SPACE DIVISION
VALLEY FORGE SPACE CENTER
GODDARD BLVD KING OF PRUSSIA
P. O. BOX 8555
PHILADELPHIA, PA 19101
    01CY ATTN M. H. BORTNER SPACE SCI LAB

GENERAL ELECTRIC COMPANY
TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET (P.O. DRAWER QQ)
SANTA BARBARA, CA 93102
01CY ATTN DASIAC
01CY ATTN DON CHANDLER
01CY ATTN TOM BARRETT
01CY ATTN TIM STEPHENS
01CY ATTN WARREN S. KNAPP
01CY ATTN WILLIAM MCNAMERA
01CY ATTN B. GAMBILL
01CY ATTN MACK STANTON

GENERAL RESEARCH CORPORATION
P. O. BOX 3587
SANTA BARBARA, CA 93105
01CY ATTN JOHN ISE JR
01CY ATTN JOEL GARBARINO

GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
FAIRBANKS, AK 99701
(ALL CLASS ATTN: SECURITY OFFICER)
01CY ATTN T. N. DAVIS (UNCL ONLY)
01CY ATTN NEAL BROWN (UNCL ONLY)
01CY ATTN TECHNICAL LIBRARY

GTE SYLVANIA, INC.
ELECTRONICS SYSTEMS GRP-EASTERN DIV
77 A STREET
NEEDHAM, MA 02194
01CY ATTN MARSHAL CROSS

INSTITUTE FOR DEFENSE ANALYSES
400 ARMY-NAVY DRIVE
ARLINGTON, VA 22202
01CY ATTN J. M. AEIN
01CY ATTN ERNEST BAUER
01CY ATTN HANS WOLFHARD
01CY ATTN JOEL BENGSTEN

HARRIS CORP, E.S.D.
P. O. BOX 37
MELBOURNE, FL 32901
01CY ATTN ADV PROG DEPT DR. CARL DAVIS

HSS, INC.
2 ALFRED CIRCLE
BEDFORD, MA 01730
    01CY ATTN DONALD HANSEN

INTL TEL & TELEGRAPH CORPORATION
500 WASHINGTON AVENUE
NUTLEY, NJ 07110
    01CY ATTN TECHNICAL LIBRARY

JAYCOR
1401 CAMINO DEL MAR
DEL MAR, CA 92014
    01CY ATTN S. R. GOLDMAN

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
    01CY ATTN DOCUMENT LIBRARIAN
    01CY ATTN THOMAS POTEMRA
    01CY ATTN JOHN DASSOULAS

LOCKHEED MISSILES & SPACE CO INC
P. O. BOX 504
SUNNYVALE, CA 94088
    01CY ATTN DEPT 60-12
    01CY ATTN D. R. CHURCHILL

LOCKHEED MISSILES AND SPACE CO INC
3251 HANOVER STREET
PALO ALTO, CA 94304
    01CY ATTN MARTIN WALT DEPT 52-10
    01CY ATTN RICHARD G. JOHNSON DEPT 52-12
    01CY ATTN BILLY M. MCCORMAC DEPT 52-54

KAMAN SCIENCES CORP
P. O. BOX 7463
COLORADO SPRINGS, CO 80933
    01CY ATTN B. J. BITTNER

LINKABIT CORP
10453 ROSELLE
SAN DIEGO, CA 92121
    01CY ATTN IRWIN JACOBS

M.I.T. LINCOLN LABORATORY
P. O. BOX 73
LEXINGTON, MA 02173
01CY ATTN LIB A-082 FOR DAVID M. TOWLE
01CY ATTN MR. WALDEN X113
01CY ATTN JAMES H. PANNELL L-246
01CY ATTN D. CLARK

MCDONNELL DOUGLAS CORPORATION
5301 BOLSA AVENUE
HUNTINGTON BEACH, CA 92647
01CY ATTN N. HARRIS
01CY ATTN J. MOULE
01CY ATTN GEORGE MROZ
01CY ATTN BILL OLSON

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
01CY ATTN P. FISCHER
01CY ATTN W. F. CREVIER
01CY ATTN STEVEN L. GUTSCHE
01CY ATTN D. SAPPENFIELD
01CY ATTN R. BOGUSCH
01CY ATTN R. HENDRICK
01CY ATTN RALPH KILB
01CY ATTN DAVE SOWLE
01CY ATTN F. FAJEN
01CY ATTN M. SCHEIBE
01CY ATTN CONRAD L. LONGMIRE
01CY ATTN WARREN A. SCHLUETER

MITRE CORPORATION, THE
P. O. BOX 208
BEDFORD, MA 01730
01CY ATTN J. C. KEENAN
01CY ATTN G. HARDING
01CY ATTN CHIEF SCIENTIST W. SEN
01CY ATTN S. A MORIN
01CY ATTN C. E. CALLAHAN

PACIFIC-SIERRA RESEARCH CORP
1456 CLOVERFIELD BLVD.
SANTA MONICA, CA 90404
01CY ATTN F. C. FIELD JR

PHOTOMETRICS, INC.
442 MARRETT ROAD
LEXINGTON, MA 02173
    01CY ATTN IRVING L. KOFSKY

PHYSICAL DYNAMICS INC.
P. O. BOX 21589
SEATTLE, WA 98111
    01CY ATTN E. J. FREMOUW

PHYSICAL DYNAMICS INC.
P. O. BOX 1069
BERKELEY, CA 94701
    01CY ATTN A. THOMPSON
    01CY ATTN JOSEPH B. WORKMAN

R & D ASSOCIATES
P. O. BOX 9695
MARINA DEL REY, CA 90291
    01CY ATTN RICHARD LATTER
    01CY ATTN FORREST GILMORE
    01CY ATTN BRYAN GABBARD
    01CY ATTN WILLIAM B. WRIGHT JR
    01CY ATTN ROBERT F. LELEVIER
    01CY ATTN WILLIAM J. KARZAS

RAND CORPORATION, THE
1700 MAIN STREET
SANTA MONICA, CA 90406
    01CY ATTN CULLEN CRAIN
    01CY ATTN ED BEDROZIAN

SCIENCE APPLICATIONS, INC.
P. O. BOX 2351
LA JOLLA, CA 92038
    01CY ATTN LEWIS M. LINSON
    01CY ATTN DANIEL A. HAMLIN
    01CY ATTN D. SACHS
    01CY ATTN E. A. STRAKER
    01CY ATTN CURTIS A. SMITH
    01CY ATTN JACK MCDOUGAL

RAYTHEON CO.
528 BOSTON POST ROAD
SUDBURY, MA 01776
    01CY ATTN BARBARA ADAMS

SCIENCE APPLICATIONS, INC.
HUNTSVILLE DIVISION
2109 W. CLINTON AVENUE
SUITE 700
HUNTSVILLE, AL 35805
01CY ATTN DALE H. DIVIS

SCIENCE APPLICATIONS, INCORPORATED
8400 WESTPARK DRIVE
MCLEAN, VA 22101
01CY ATTN B. ADAMS

STANFORD RESEARCH INSTITUTE
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025
01CY ATTN DONALD NEILSON
01CY ATTN ALAN BURNS
01CY ATTN G. SMITH
01CY ATTN L. L. COBB
01CY ATTN DAVID A. JOHNSON
01CY ATTN WALTER G. CHESNUT
01CY ATTN CHARLES L. RINO
01CY ATTN WALTER JAYE
01CY ATTN M. BARON
01CY ATTN RAY L. LEADABRAND

SYSTEM DEVELOPMENT CORPORATION
4130 LINDEN AVENUE
DAYTON, OH 45432
01CY ATTN F. G. MEYER

TECHNOLOGY INTERNATIONAL CORP
75 WIGGINS AVENUE
BEDFORD, MA 01730
01CY ATTN W. P. BOQUIST

TRW DEFENSE & SPACE SYS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
01CY ATTN R. K. PLEBUCH R1-2078
01CY ATTN ROBERT M. WEBB R1-1150

VISIDYNE, INC.
19 THIRD AVENUE
NORTH WEST INDUSTRIAL PARK
BURLINGTON, MA 01803
01CY ATTN CHARLES HUMPHREY
01CY ATTN J. W. CARPENTER